CHAPTER 4
REPORT OF THE POWER SUBSYSTEMS PANEL

INTRODUCTION

A representative cross-section of space power specialists deliberated for three days with the common objective of identifying a prioritized list of recommended technology thrusts for the NASA Office of Aeronautics and Space Technology. The group consisted of representatives from NASA, DOD, COMSAT, and industry, representing primarily the segment of the space power peer group responsible for spacecraft power system. The strategy was for each participant to bring to the meeting a paper and presentation describing specific problems encountered by his particular organization wherein technology improvement could have either avoided or minimized the problem. The thrust of these presentations were to (1) identify various problems and inadequacies in the past and ongoing spacecraft power system design, test, integration, and operation, and (2) define necessary solution(s) via supporting technology development work required. Most specific problems naturally related to past space flight experience but essentially all had merit with respect to ongoing or future planned spacecraft. Every participant entered into vigorous discussion describing in great detail specific problems, which was the primary contributing element to the highly successful meeting. After hearing all the problem details, there was very little problem establishing the prioritized list of specific recommendations with essentially no minority reports needed.

The overall approach taken in the workshop was composed of three basic steps:

1) Identify Technology Problem areas being encountered in present systems.

2) Translate the Technology Problems into Technology Development Requirements.

3) Prioritize the Technology Development Requirements to establish a basis for NASA planning and work recommendations.

The following sections describe these steps and the results obtained.

TECHNOLOGY DEVELOPMENT PROBLEM AREAS

Following the problem and recommended study-area discussions presented during the workshop, the workshop participants translated the problems into technology problem statements and listed them for consideration as needed work.

A ground rule followed was that needed work should not be identified for Advanced Systems such as Space Power Systems or large space platforms. The emphasis was placed on present and near term problems and needs. Specific direction to avoid priorities at this stage was imposed to assure full participation by the entire workshop.

The specific technology problems were posted under the following electrical power technology areas:

1) Power System
2) Solar Array
3) Battery
4) Power Distribution (switching, fault protection, cables, high voltage)
5) Power Conditioning Electronics
6) High Voltage Power Supplies
7) Power Transfer
8) General Problems (data, qualified parts, etc.)

The listing of problem areas/technology needs and needed engineering tool improvements was very large. The workshop panel then proceeded to group the problems in an attempt to combine and reduce them into viable work categories as follows:

1) Substorm and Plasma Design Data
2) Modeling of Subsystem and Components
3) Power System Monitoring and Degraded System Management
4) Development of Engineering Data Base on New Technology Items
5) New Component Development Needs
6) Rotary Joints for Transmission of Power and Signals
7) Ni-Cd Battery Manufacturing and Application Technology
8) On-Array Power Management
9) High Voltage Technology Development
10) Solar Array/Solar Cell Testing
11) Engineering and Parts Standardization and Testing Standards
12) Interdiscipline Problems

The collection of problems in this format is reported in the next section.

Substorm and Plasma Design Data

The newly defined existence of plasma trapped in the Earth's magnetic field and its possibly catastrophic effect on high voltage, high power solar arrays points up an urgent need to adequately define the substorm environment so that solar arrays can be designed to survive this environment with minimum degradation.

Modeling of Subsystem and Components

Existing full-up analytical power system models are inadequate. Further, as the power system grows in complexity, the design and power management problems are amplified. Coupling this with extreme complications for complete end-to-end checkout of the power system implies that use of this tool is becoming a mandatory requirement for understanding and predicting performance margins.

In particular, accurate dc and ac models of each power subsystem component are required. Such models presently do not exist for solar arrays and batteries. Needed is a detailed analytical model of the ac (transient and small signal ac) performance for solar arrays. Immediate problems on Dynamic Explorer and Solar Maximum Mission that are related to the inability to test large arrays demonstrate the need for such models. Large arrays are too large to deploy and illuminate, and lightweight structures may even be too fragile to deploy in the presence of gravity. Once a model has been generated, it will be possible to design and build adequate simulators so that the overall power subsystem can be more fully tested. Also a detailed model of nickel cadmium batteries for both ac and dc conditions is required. Immediate problems of on-orbit failures suggest that the electrochemical system is poorly understood. As a result, power subsystem designs do not provide for all of the batteries' characteristics.

Power System Monitoring and Degraded System Management

The sensor complement used for power system monitoring is inadequate. All too often we have too few diagnostic techniques to accurately isolate the causes of problems. More sensitive and expanded sensors are needed for monitoring battery cell voltages, ampere-hour integration, charge/discharge current, relay and power transfer switch states, solar array power, and load current sensing. Automatic power system control should be supported, e.g., MSFC's Programmable Power Processor (PPP) and JPL's Auxiliary Power Subsystem Model (APSM).

Development of Engineering Data Base on New Technology Items

Because of project pressures to utilize increased solar cell efficiency (latest cell technology), the cell and cover characterization data concerning radiation and lifetime performance has not yet been generated or verified. This design data is necessary for today's array designs.

The Ni-Cd battery has a solid data base, but little if any of this type data baseline is available for the $Ni\text{-}H_2$ cell. Until it is available, $Ni\text{-}H_2$ battery programs will be difficult to sell to flight projects.

Power MOS devices are currently available from the manufacturers, but there has been no effort to qualify these units for flight in spite of their switching and low gate power advantages. The big question is their radiation susceptibility.

Microprocessors are going to be necessary for any housekeeping and management of power systems within the power system. It is necessary to select universal types which are flight qualified.

There are presently few if any high voltage, high power devices which can meet present and future needs. A large technology development is needed. The rejection criteria for these devices must be formulated with a verification test program to guarantee high reliability parts in a new and difficult environment which has not been successfully reduced by high voltage instrument technology transfer. This new environment is high voltage coupled with high temperature.

New Component Development Needs

The advent of high voltage, high power systems for Solar Electric Power Subsystem (SEPS), the Power Module, the Power Extension Package, and Erectable Space Platforms points up the need for components to operate at higher voltage and current levels. The SEPS solar array is configured with modules that operate at 196 volts at peak power, and these modules can be connected in series to provide higher voltages in integral multiples of 196 volts. The initial Beginning of Life (BOL) 31.6 kilowatt power level at the lowest operating voltage produces approximately 250 amperes. Transistors, relays, capacitors, connectors, and other distribution equipment must be developed to meet these voltage and current levels. In addition, power unique components are required to measure current on the solar array (because of the use of shunt regulators on the solar array to dissipate excess power), to measure nickel cadmium battery state of charge, and to detect and protect against faults.

Rotary Joints for Transmission of Power and Signals

High voltage, high power systems add a dimension to the past problem of transmission of 28 volt power and low level signals across a rotary joint. Possible techniques include rotary transformers, flexible harnesses, and slip rings for power and signals, and rf and optical coupling for signals. Additional work must be done in this area both because of past failures and present needs.

Ni-Cd Battery Manufacturing and Application Technology

Recent and frequent incidences of on-orbit degradation and failure of nickel cadmium batteries indicate a lack of uniformity in the original product and a lack of understanding of the correct application. The specific need has been identified for nickel cadmium long life design criteria, process standardization, electrochemical quality analysis methods, and reconditioning methodology to enhance operational performance for ten to twenty years on orbit.

On-Array Power Management

On-array power management has been a requirement with little actual development having been accomplished. On-array power management is required to reduce the signal rotating interface complexity, to place the heat at panel surfaces having lightweight construction and small thermal mass, and to provide power management flexibility over individual string current, voltage and power sensing, spot thermal control, panel or string problems due to degradation or environmental interactions, and current control of array overpower or overvoltage conditions. The concept also lends itself to advanced developments such as (1) three terminal solar cells, (2) photocontrollable cover slides, or (3) liquid crystal control covers.

High Voltage Technology Development

Numerous and varied high voltage designs are failing and/or are unreliable. In fact, failure of high powered traveling wave tube amplifiers was designated by a senior Air Force spokesman as the number one problem for communication satellites. All too often these failures could have been avoided by the application of the proper design, manufacturing, and test disciplines. Missing is a complete and detailed design guide (handbook) for high voltage equipment somewhat similar to the solar array design handbook. Also required is a detailed model high voltage procurement specification. The design guide should provide a set of recommended hardware design and analysis techniques and procedures. The model specification should contain detailed test techniques, methodology and acceptance criteria for piece parts, subassemblies, and top assemblies.

Solar Array/Solar Cell Testing

A nondestructive testing technique is required to verify the integrity of welds used to interconnect solar cells on high power solar arrays. Over one million welds are required in a large array. Various techniques have been utilized such as infrared scanning, laser holography, X-ray, and resistivity measurements, but these techniques are both expensive and inadequate.

Recent major problems have been encountered in applying "standard" humidity tests as process control tests. These tests are run at elevated temperatures in high humidity to accelerate corrosion of the contacts if impurities enter the contact processes. These tests are not compatible with new high efficiency solar cells with back surface reflectors. No viable alternate process control test is available. A new test (or tests) needs to be developed and standardized for the new solar cells being implemented into hardware programs.

Engineering and Parts Standardization and Testing Standards

There appears to be a general industry-wide lack of standard or baseline data base for many of the power system related parts and components. This is principally lacking in testing techniques which are used as standard by the industry principally in battery cells, solar cells, and their process and control development. Discussion centered on generating guidelines and technology leadership from NASA. Nondestructive testing techniques for welded contacts and contact corrosion accelerated testing were raised as problems associated with this lack of technical leadership.

Interdiscipline Problems

Two power subsystem problem areas have been identified which involve technology in areas not covered by this workshop panel.

The high power levels and the drive to reduce weight have resulted in very lightweight structures to support large area solar arrays. These structures have very low natural frequencies and will interact with the attitude control system.

Thermal control systems of existing spacecraft have failed to maintain the nickel cadmium batteries at the required temperature range, either because of a lack of understanding of battery dissipation or an inadequate thermal design.

SUMMARY OF RECOMMENDATIONS

The recommendations made of the members of the Power Subsystems Panel are summarized in the following paragraphs.

Substorm Plasma Effects

1) A simulation of the space plasma environment must be developed for ground testing of effects on electrical power systems. A determination is to be made of the energy profile, where it will flow, and how it will be dissipated in the spacecraft systems.

2) It is recommended that the spacecraft charging program at Lewis Research Center be supported by adding this study element to their program.

Analytical Modeling of Power System and Its Components

1) Perform alternating current modeling of the major power subsystem components by analysis. Verify by test, collecting sufficient data points to validate the analytical models assumed for the solar array, battery, and power conditioning and distribution. Define frequency range over which testing should be performed. Synthesize individual components into a single analytical model of a power system.

2) Define a set of parameters necessary to implement electronic simulation of an alternating current model of a solar array.

Improved Monitoring and Operation of Power System

1) Develop improved on-board techniques for monitoring and controlling operation of the power system and its major elements.

a) Develop software and/or hardware techniques that result in minimum impact to the spacecraft data handling/command system and to ground operations. For instance, reconfigure telemetry format for specific mission phases.

b) Identify required diagnostic measurements to allow determination of power system state of health.

c) Develop sensors and/or sensing techniques for detecting partial failure or degradation of key components such as battery, solar array, and power conditioning. Parameters to be directly measured or calculated shall include:

- Battery depth of discharge and state of charge
- Battery cell voltages
- Solar array parameters to include partial shunt currents and subarray currents and voltages

- Solar array output power and maximum available power
- Power distribution bus voltages, current, and power
- State (position) of all relays

2) Define techniques for reducing the complexity of managing degraded power system and components from ground and thereby minimize reliance on ground analysis and control.

Engineering Data Base Development

1) Develop an engineering data base on emerging technologies.

New Component Development Needs

1) High voltage, high power components are required for immediate use on flight power systems. These parts must be developed; new, reliable screening techniques determined; and flight qualification accomplished.

2) Specific items recommended include:

a) Families of switches and resettable circuit breakers over the following ranges:

500 V dc, 300 V dc, 150 V dc
10, 25, 50, 100, 150 amps

b) Capacitors, polarized, energy storage high capacitance voltage filter at greater than 150 V dc

c) Connectors, power wiring, slipjoint power, 300 V, 600 V, 1 kV dc

d) HV signal components

300 V, 600 V, 1 kV dc

Rotary Joint for Transmission of Power and Signals

1) Develop a combination rotary power and duplex transformer configured to provide 500 wattage (electrical) with data channels operating in the megabit range and in a parallel digital simplex mode for increased reliability and reduced noise.

Nickel-Cadmium Battery Manufacturing

1) Continue (with high priority) technology development for reconditioning and cell manufacturing process optimization and standardization.

2) Modify on-going process selection and standardization work to emphasize electrochemical and physical analysis methods development needed to provide better understanding of electrochemical fundamentals of plate processes, process variability and quality control, and charge/discharge processes.

High Voltage Technology Development

1) Develop a detailed HV design guide handbook and a model detailed HV procurement specification for spacecraft applications.

2) The design guide should provide a set of recommended hardware design and analysis techniques and procedures. It should also contain a detailed parametric materials properties data base and recommended test procedures and techniques for obtaining the necessary materials data.

3) The model specification should contain detailed test techniques, methodology and acceptance criteria for piece parts, subassemblies and top assemblies. It should also contain requirements for the types and detail of analytical techniques necessary to verify each design.

Array Interconnect Process Control, Product Verification, and Accelerated Life Testing

1) Continue (with high priority) the development of specific techniques for controlling the process involved in making reliable interconnections, for verification of flight hardware interconnect integrity, and for conducting accelerated corrosion testing on solar cell interconnects.

PRIORITIZED RECOMMENDATIONS FOR POWER SUBSYSTEMS

After the individual technology items were developed and the recommendations formulated, a prioritization was initiated. Factors which were to be considered were discussed. These factors included payoff (present need or future need), risk, and cost effectiveness. Since some items appeared to have

essentially equal priority, it was concluded that grouping of degree of priority was needed, rather than absolute ordering of the 10 items in the list. Detailed discussion of the recommendations and rationale resulted in the following listing.

High Priority Items:

- Highest emphasis on new technology items -

  1) Modeling of Subsystem and Components
  2) Power System Monitoring and Degraded System Management
  3) New Component Development Needs
  4) High Voltage Technology Development

- Continue activity with existing program -

  Substorm and Plasma Design Data

- Modify existing program -

  Ni-Cd Battery Manufacturing and Application Technology

- Increase emphasis on ongoing activities -

  Solar Array/Solar Cell Testing

Medium Priority Items:

- Development of Engineering Data Base on New Technology Items

- Rotary Joints for Transmission of Power and Signals

Low Priority Items:

- On-Array Power Management

Not Technology Development:

- Engineering and Parts Standardization and Testing Standards

- Interdiscipline Problems